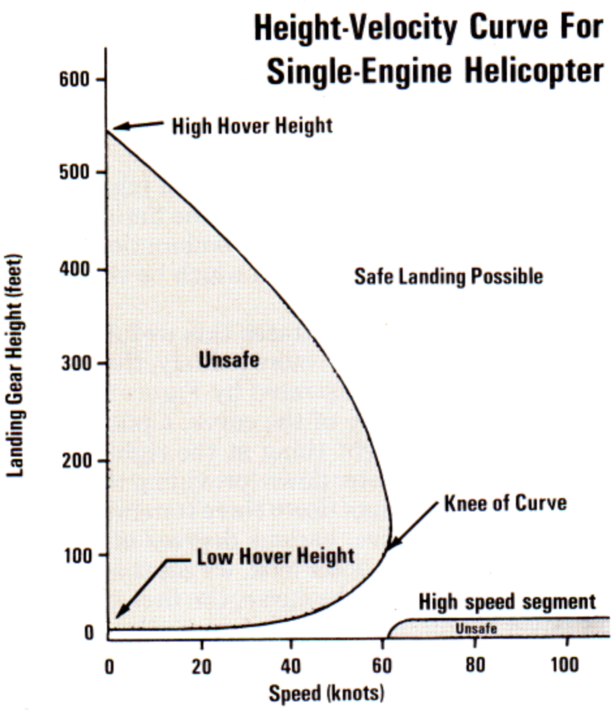
COPING WITH A POWER FAILURE
THE HEIGHT-VELOCITY DIAGRAM

No matter how clever the pilot is in juggling the energy in both the entry into and the flare from autorotation, there remain some combinations of initial altitudes and speeds from which he will surely crash.

The figure that illustrates this awful truth is the Height-Velocity Diagram, or "Deadman's Curve." Along the boundary of this curve, a pilot should be able to do the right thing at the right time to safely set the helicopter down (providing that there is a decent landing spot down there somewhere) but from inside the curve, various degrees of damage will occur.



Low Hover Height

Taking a closer look, we see that several definite points define the curve, the first being the low hover height. Up to this height, the pilot can handle a power failure in hover by coming straight down and using collective pitch to cushion the landing as the rotor slows down. Above that point, the rotor will either slow down and stall if the pilot does not reduce collective pitch--or the helicopter will hit too hard if he does.

The low hover height can be raised by any of the following changes: decrease the power required to hover; increase the rotor inertia; increase the blade area so that a lower speed is required to stall; and, finally increase the capability of the landing gear to absorb energy without damage.

High Hover Height

The dangerous hover altitude runs up from the low hover height to the high hover height. At this second point, there is enough altitude to make a diving transition into forward flight autorotation and execute a normal power-off flare.

Forward Flight

A power failure in forward flight is also perilous--but not quite as much as in hover, since it is easier to get into forward flight autorotation. At speeds greater than the knee of the curve, a power failure should be survivable at any altitude--except possibly right on the deck.

Establishing the Diagram

The height-velocity diagram shown in the operator's manual for each type of helicopter has been established by skilled test pilots who tried to make their reactions simulate average pilots. This was done, in part, by specifying a definite delay time following the power chop before moving the controls. This delay time depends on who is writing the rules.

When certificating a helicopter for the FAA, the bottom of the curve is established in a full-power climb with "normal" pilot reaction time between power chop and collective reduction. This accounts for the degree of alertness that should exist close to the ground. The top of the curve is established for level-flight power and a delay of normal pilot reaction plus one second. The military, on the other hand, assumes that their pilots may be distracted by other duties during an engine failure and will not react in less than two seconds in any flight condition.

Whether the specified delay should be applied to the pedals and cyclic stick as well as the collective stick is another subject of debate. Conservatively, it should, but realistically, it can be assumed that the pilot will almost instantaneously react to sudden yaw, pitch, and roll motions from an engine failure just as he would if these motions were caused by turbulent air.

Factors affecting size of diagram

The size of the height-velocity diagram depends on several factors. For a given helicopter, increasing the gross weight and density altitude both expand the unsafe region. As a rough rule-of-thumb, a diagram established at sea level can be considered to expand like a balloon directly as gross weight goes up, and inversely as the air density decreases. For example, simultaneously increasing gross weight by 20% and going to 10,000 feet where the air is only 74% as dense as at sea level would give an expansion factor of 1.6. On the figure, the high hover point would go from 540 to 900 feet, the knee of the curve would increase from 60 to 100 knots, and the low hover point would drop from 15 to 9 feet. For different helicopters, the greater the disc loading, the higher the high hover point--up to 1,000 feet on some modern designs.

If the helicopter is already descending, such as on a landing approach, the collective pitch is already low and the unsafe region on the Deadman's Curve is reduced.

A separate way to reduce the size of the curve is by using a very high inertia rotor. This came naturally with such tip-jet powered helicopters as the Dutch Kolibri and the French Djinn. (I have been told that the Djinn could make a power-off landing --and *then take off*, fly 100 yards, and make another landing before the rotor wound down.) Bell Helicopter Textron once demonstrated the elimination of the unsafe region of the height-velocity diagram on a Model 206L by adding enough tip weights to more than double the normal rotor inertia. Other suggestions include standby tip rockets or a high-speed flywheel to furnish that little bit of energy just when it is needed most.

High-speed segment

The high-speed portion of the height-velocity diagram merely warns you of the obvious--it is dangerous to fly low and fast, and a power failure is just one circumstance that could lead to an accident in this regime. Over the years, the top part of this segment has been lowered and a survey of operator's manuals shows the following interesting trend:

Helicopter	Year Certificated	Height of Boundary
Bell 47J-2	1959	50
Bell OH-4A	1963	15
Hughes 500	1964	5

As a matter of fact, the rotor has a flapping characteristic that benefits the unfortunate pilot who has an engine failure at high speed. As the rotor slows down, its tip speed ratio increases and it flaps back. This produces a nose-up pitching moment that will automatically start the helicopter into a climb. This automatic climb may not last very long and the nose-up attitude might cause the tail to strike the ground--but you must agree that it beats an automatic dive.

With sufficient speed during a power failure, the climb can be deliberately prolonged to result in an appreciable gain in altitude as speed is bled off. This zoom maneuver can greatly widen the area available for a safe touchdown. A standard demonstration on the OH-6A entailed chopping the power while flying at a five-foot altitude at maximum speed ant then climbing high enough to make two 360^0 turns before landing in autorotation.

Multi-Engine Helicopters

Another major effect on the height-velocity diagram is the number of engines--if we assume that only one will fail at a time. (Simultaneous fuel starvation can usually be avoided by having separate fuel tanks supply each engine and by using fuel lines of unequal length.) Single-engine power in most twin-engine helicopters is not sufficient to completely eliminate the unsafe region, but it can shrink it considerably and produce another boundary--one outside of which the helicopter does not have to land but can fly away on the remaining power.

We should recognize, however, that the height-velocity diagram applies to more than loss of power--it also accounts for tail-rotor loss. In that case, the pilot would remove all power from the main rotor no matter how many engines he had.

From *Rotor and Wing* April 1981 and Chapter 16 of *Helicopter Aerodynamics*